Invited Paper

Particle-trapped near-field scanning optical microscopy: scattering and depolarization

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ABSTRACT

Particle-trapped near-field scanning optical microscopy utilises a laser-trapped dielectric or metallic particle as a near-field scatterer to probe the high spatial frequency information from a sample. Scattering and depolarization by a trapped particle in an evanescent wave are two important issues in such an imaging system. These two issues are addressed in this paper. The strength of scattered evanescent waves was measured for particles of different sizes (0.1 μm to 2 μm in diameter) and different materials (polystyrene, gold and silver). It has been found that the signal strength of scattered evanescent waves increases appreciably with the size of a particle. As a result, image contrast is improved significantly with laser-trapped metallic particles of large size. It has also been found that the depolarization of scattered evanescent waves under s polarised illumination is stronger than that under p polarized beam illumination, and that image contrast of the evanescent wave interference pattern can be improved by a factor of 3 with a parallel analyser under s polarized beam illumination. This result suggests that less depolarized scattered evanescent photons carry more information of an object and should be utilised for the imaging in particle-trapped near-field scanning optical microscopy.

Key words: laser trapping laser scanning imaging, near-field microscopy, Mie scattering, biophotonics.

1. INTRODUCTION

Particle-trapped near-field scanning optical microscopy utilises a laser-trapped dielectric or metallic particle as a near-field scatterer to probe the high spatial frequency information from a sample [1]. Compared with other types of probes used in near-field microscopy, a probe produced by a trapped particle has a number of advantages including high resolution (which is mainly determined by the contacting part of a laser-trapped particle), improved image contrast (which can be controlled by the scattering properties of a trapped particle), high signal-to-noise ratio (which results from the use of a high numerical aperture objective), and optically remote control (which allows the imaging system suitable for biological imaging). The use of a trapped metallic particle [2-4] can enhance transverse trapping force, leading to high scanning speed in near-field imaging. In addition, scattering efficiency can be enhanced using a trapped metallic particle due to high reflection and surface plasmon excitation, which results in high contrast and high signal-to-noise ratio in near-field imaging.

The rapid development of particle-trapped near-field scanning optical microscopy requires comprehensive understanding of scattered evanescent waves with particles. Scattering and depolarization of evanescent waves by a trapped particle are two important issues in such an imaging system. The strength of scattered evanescent waves was measured for particles of different sizes (0.1 μm to 2 μm in diameter) and different materials (polystyrene, gold and silver) [5, 6]. It has been found that the signal strength of scattered evanescent waves increases appreciably with the size of a particle. As a result, image contrast is improved significantly with laser-trapped metallic particles of large sizes. The effect of depolarisation of scattered evanescent waves plays a significant role in particle-trapped near-field microscopy. It has been found that the depolarization of scattered evanescent waves under s polarized illumination is stronger than that under p polarized beam illumination, and that image contrast of the evanescent wave interference pattern can be improved by a factor of 3 with a parallel analyser

In *Optical Sensing, Imaging, and Manipulation for Biological and Biomedical Applications*, Robert R. Alfano, Ping-Pei Ho, Arthur E. T. Chiou, Editors, Proceedings of SPIE Vol. 4082 (2000) • 0277-786X/00/$15.00

under s polarized beam illumination [7]. This result suggests that less depolarized scattered evanescent photons carry more information of an object and should be utilised for the imaging in particle-trapped near-field scanning optical microscopy. The effect of scattering and depolarization on near-field imaging with a laser-trapped particle is discussed in this paper. The detail of the experimental setup has been explained in our previous papers [5-7].

2. EFFECT OF SCATTERING

Because the strength of scattered signal by a trapped gold particle is increased significantly [5], image contrast should be improved accordingly. This feature has been demonstrated by imaging the evanescent wave interference pattern [5]. In Fig. 1, images of the surface ($\lambda/4$) of a BK7 prism are shown. The incident laser for producing evanescent waves (He-Ne laser) was p polarized. In the case of using a confocal scanning microscope (Olympus: FluoView), no clear detail of the surface structure was observed (Fig. 1a), while it can be observed using a trapped particle (Figs. 1b and1c). The contrast of the imaged structure is enhanced when a trapped gold particle was employed, as expected.

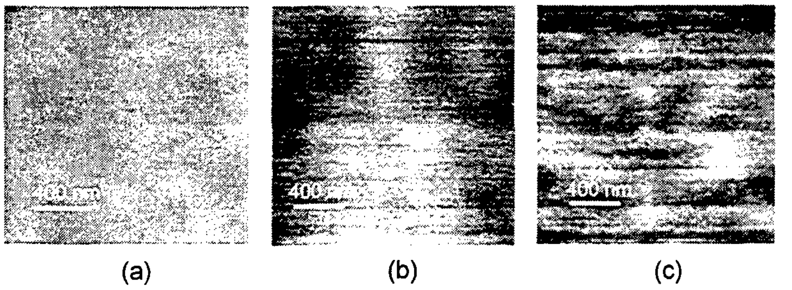

Fig.1 Images of the surface of a BK7 prism with a laser trapped particle of diameter 100 nm: (a) confocal image; (b) dielectric particle; (c) gold particle.

3. EFFECT OF DEPOLARIZATION

As has been pointed before, less depolarized photons scattered by a trapped particle carry more information of an object under inspection [7]. Therefore, it is very important to understand the dependence of the degree of polarization of the scattered signal. Fig. 2 shows the degree of polarization of the scattered evanescent wave by a dielectric particle as a function of the particle size [6]. The degree of polarization increases with the particle size, as may be expected from Mie scattering theory [8]. However, for a particle larger than 500 nm, the degree of polarization under p polarized illumination is higher than that under s polarized illumination; otherwise the situation is reversed.

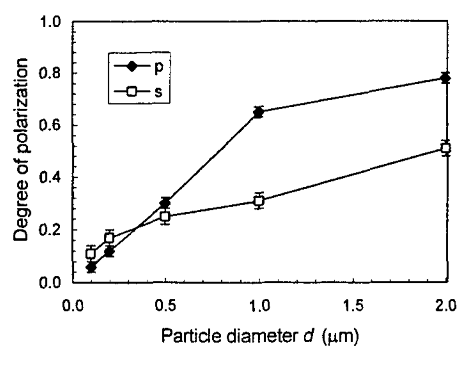

Fig. 2 Degree of polarization for a dielectric particle.

In Fig. 3, the measured dependence of the degree of polarization on the particle size for a trapped gold particle is depicted. Clearly, it is different from Fig. 2 in that the degree of polarization for a gold particle decreases with the particle size in particular for p polarized illumination. This phenomenon is not expected from Mie scattering theory [8]. It may be related to surface plasmon excitation associated with a small metallic particle, which enhances the evanescent wave near the trapped metallic particle [9].

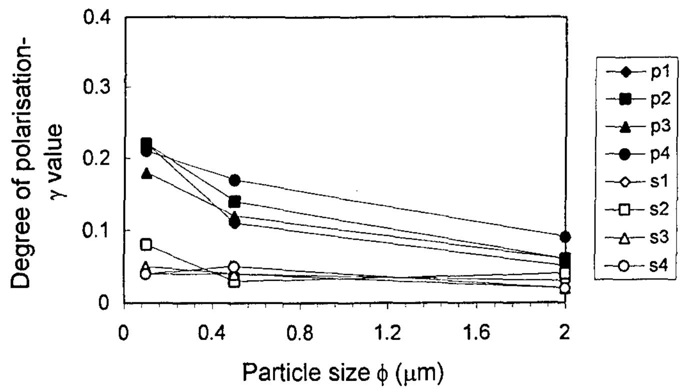

Fig. 3 Degree of polarization for a gold particle. p1, p2, p3, and p4 correspond to p polarized illumination at 4 different incident angles of the He-Ne laser. s1, s2, s3, and s4 correspond to s polarized illumination at 4 different incident angles of the He-Ne laser.

4. CONCLUSION

We have demonstrated in Fig. 1 that the enhanced signal leads to the improvement in image contrast in particular when a gold particle is used. It can be concluded from Figs. 2 and 3 that it is advantageous to use a small gold particle illuminated by a p polarized evanescent wave because scattered evanescent photons are less depolarized compared with the use of an s polarized beam. In the latter case, polarization gating [7] is needed to remove those highly depolarized photons. Further theoretical work based on the multiple-multipole method is needs to understand the different behaviour of the degree of polarization between dielectric (Fig. 2) and metallic (Fig. 3) particles.

ACKNOWLEDGEMENTS

The author thanks the Australian Research Council for its support. Special thanks are given to Mr. Puchun Ke who conducted the detailed experimental work on this topic at Victoria University.

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